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VISUAL SEARCH IN AIR COMBAT

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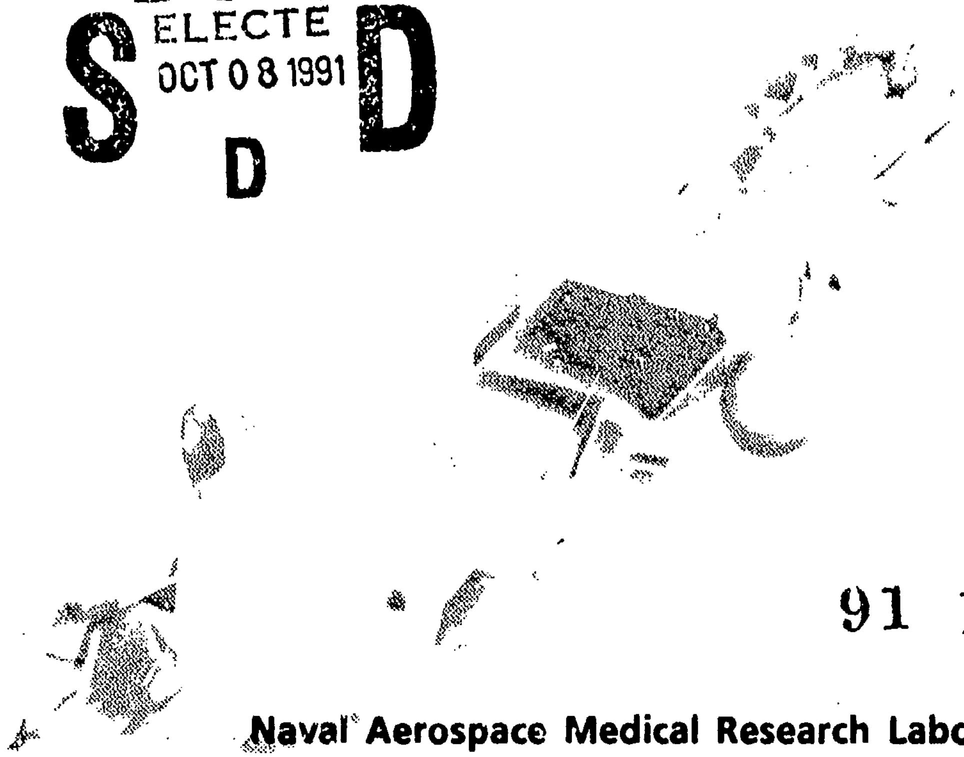

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Visual search and detection remains as the most important sensor for the aircrew of tactical aircraft. Detection of airborne targets is directly related to the combat effectiveness of the fighter/strike mission. This monograph, the product of a coordinated effort between the Naval Aerospace Medical Research Laboratory (NAMRL) and the Navy Fighter Weapons School (NFWS), TopGun, covers the basics required to optimize visual search in combat. The document is intended as an instructional aid to aircrew of tactical aircraft, especially those involved in aerial combat. The following four topics are discussed in this monograph: (a) sensors: means of detection; (b) equipment: obstructions to vision; (c) detection: the eye as a sensor; and (d) search: using the sensor.

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ABSTRACT

Visual search and detection remains as the most important sensor for aircrew of tactical aircraft. Detection of airborne targets is directly related to the combat effectiveness of the fighter/strike mission. This monograph, the product of a coordinated effort between the Naval Aerospace Medical Research Laboratory (NAMRL) and the Navy Fighter Weapons School (NFWS), TopGun, covers the basics required to optimize visual search in combat. The document is intended as an instructional aid to aircrew of tactical aircraft, especially those involved in aerial combat. The following four topics are discussed in the monograph: (a) sensors: means of detection; (b) equipment: obstructions to vision; (c) detection: the eye as a sensor; and (d) search: using the sensor.

INTRODUCTION

The eye remains as the most important sensor for aircrew of tactical aircraft. Its importance to visual search and detection has not changed since the early days of air combat. A fighter who loses sight of or never detects the enemy can quickly succumb to hostile fire. Regrettably, this lesson has been learned too many times. Simply put, with inadequate visual search in today's multithreat environment, the chance of survival is greatly diminished.

As technology advances, we will rely more and more on passive sensors and visual search. This will be the case in a full-stealth environment. The radar cross section of an aircraft will be a fraction of what it is in today's fighters. Detection using conventional radar will be difficult and likely to occur at a greatly reduced range. The aircraft that illuminates first will be quickly detected and targeted by accurate, state-of-the-art passive sensors. The importance of visual detection has not diminished with technological advances.

This monograph will concentrate on the effective use of visual search by aircrew of fighter/strike aircraft. It reviews the basic principles of detection in the high-workload environment of air combat. It results from a coordinated effort between the Naval Aerospace Medical Research Laboratory (NAMRL) and the Navy Fighter Weapons School (NFWS), also known as TopGun. While the detection of airborne targets is directly related to the combat effectiveness of the fighter/strike mission, aircrew of all tactical aircraft will benefit from the information presented herein:

a. Sensors: means of detection.
b. Equipment: obstructions to vision.
c. Detection: the eye as a sensor.
d. Search: using the sensor.

SENSORS: MEANS OF DETECTION

Four categories of sensors are available to aircrew for the detection of aerial targets: onboard tactical radar, onboard threat warning receivers, radio communications (wingman, GCI, etc.), and aircrew visual search. The inherent advantages and disadvantages of each are briefly reviewed.

Onboard Radar

The onboard radar system has the capability of searching, interrogating, and tracking aircraft within its scan volume. It can do this at ranges far greater than that of visual detection. With a radar lock, the head-up display can superpose a box/diamond over the targeted aircraft to assist visual acquisition. However, this 'single target track' mode ties up the radar's search capability and leaves it with very limited capability to search and detect aircraft within 5 miles of the fighter. The pilot has some capability to achieve radar assisted visual detection when the radar is operating in its search mode. This requires a knowledge of angular reference points around the cockpit and an effective search technique. **The radar system has no capability to detect an incoming air-to-air missile.**

The most important inherent disadvantage of the onboard radar becomes apparent when one considers its maximum search area. Typically, this would approximate a 60-degree cone. This represents less than 10% of the total search area around the aircraft. To put this in another light, 90% of the sky remains untouched by that multimillion-dollar machine in the front of the aircraft (see Fig. 1).

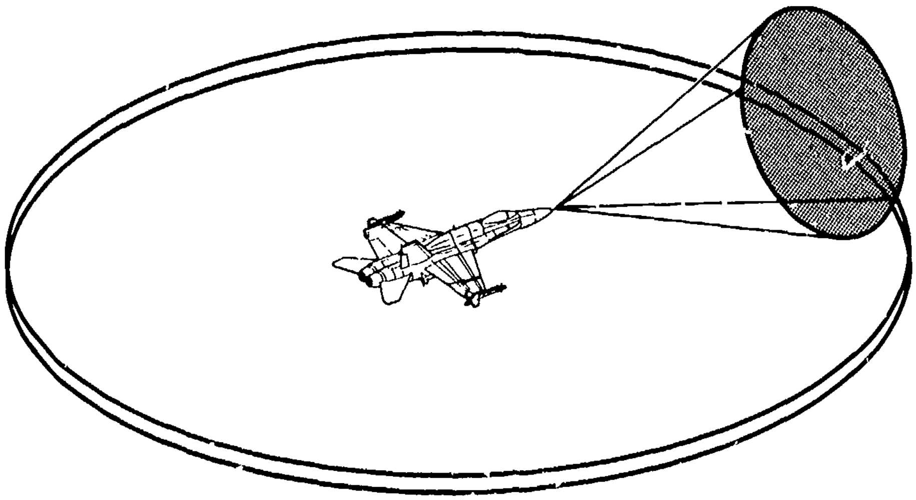

Figure 1. The search area of tactical airborne radar represents less than 10% of the total search field around an aircraft.

A television camera system, such as the one in F-14 aircraft, gives the aircrew an additional sensor. It can facilitate a 'beyond visual range' shot when positive visual identification is required. Without this equipment, a visual identification often requires the two aircraft to approach within 1 mile or less. This television system cannot be used to perform free search because of its narrow 15-degree gimbal li. ' ·.

Onboard Threat Warning Receiver

Threat warning receivers were designed primarily to warn against ground-based radar threats. They have limited air-to-air application. The technology is available for more advanced airborne threat interrogation, but this has not yet been incorporated into fleet aircraft. The best that current warning receivers can do in the air-to-air environment is to alert the aircrew of a potential threat within a given sector. Even then, the aircrew must still detect aircraft visually to employ effective countertactics.

Radio Communications (Wingman, GCI, Etc.)

All fighter/strike aircrew recognize the value of a wingman for threat detection and mutual support. Even though the wingman will be using the same sensors as the pilot, search effectiveness is multiplied by splitting responsibilities; more will be said about this later. An incoming missile is far easier to spot when the plume is viewed for the wingman to report the siting from the side (by the wingman) than when seen head-on; however, radio communication is essential.

Similarly, another aid to detection, which also relies on radio communications, is the ground/airborne radar control. These radar systems have the capability of scanning the fighter's entire hemisphere. This global view can be of great benefit but is dependent upon several criteria. The radar needs to be fully operational, and it must illuminate the fighters. The controller must have the situational awareness to give the fighters what they need when they need it. Planned emissions blackout or mutual communications jamming would eliminate the advantages of this means of detection.

Aircrew Visual Search

The use of the human eye to detect target aircraft or missile threats is termed visual search. Vision has its limitations, such as relatively short range and poor detection at night or in the clouds, but, as a system, it is almost always functional and ready for use. Vision is the only positive means to check the airspace around the fighter's aircraft. Visual search and detection is a complex procedure that requires continuous training and must be thoroughly integrated into the fighter pilot's game plan. **Fighters must always strive for total awareness of the space around their aircraft.** This is primarily accomplished by visual search.

EQUIPMENT: OBSTRUCTIONS TO VISION

Effective visual search requires a clear, unobstructed view of the target. A properly fitting helmet is required that will not restrict vision or slide around under g-forces. The mask cord should be secured so that it will not snag while the pilot twists his head around during visual search.

The decision to use a dark visor or sunglasses is a personal one. Either one **can reduce** the ability to detect a target at maximum range (1). Visual acuity improves with an increase in luminance up to about 1000 candelas per meter squared, then falls off. This translates to optimum acuity at a light level equivalent to daylight outdoors on a cloudy day. Standard-issue aviator sunglasses and visors (with 12% transmission) will reduce bright sunlight to about this level but will reduce acuity if the sky is not bright enough. As a rule of thumb, if the light is so bright that it causes discomfort, you should probably be using the sunglasses or visor. If there is no discomfort without these filters, don't use them.

Clear canopies and windscreens are vitally important. A dirty or scratchy canopy can greatly reduce the relative contrast of the target and, hence, detection ranges. Avoidable problems include paint overspray and scratches from improper polishing or cleaning. Protect the canopy like a fine pair of glasses.

The largest obstruction to vision is the fighter aircraft. It occupies almost half of the visual hemisphere. In addition to looking around the canopy bow, the fighter needs to move his aircraft to see below and aft. Dropping a wing, first one direction then the other, will fill in these gaps in the search field.

The fighter should continually practice putting his "<u>head on a swivel</u>." This will prevent him from being his own worst obstruction to vision. With a wingman, perform a simple tail chase as time and fuel dictate. With the harness unlocked, turn around as much as the cockpit will allow and practice looking over the other shoulder. This will also demonstrate how to <u>adjust the seat</u> for the best rear vision. In a similar fashion, check all equipment for optimum visual performance. Fly with the lap straps tightly fastened. Loose lap belts have been implicated in several spin accidents.

DETECTION: THE EYE AS A SENSOR

<u>Fixations</u>

When not tracking a moving target, voluntary eye movements are made up of a series of discrete fixations called "saccades." You can demonstrate this for yourself. Get a friend to track your moving finger and observe his eyes. You will see a smooth movement that corresponds to the movement of your finger. Now, hold still and ask him to make the same eye movements without the moving target. He may think that he is doing it, but if you observe closely, you will see that his eyes make a series of discrete "jumps." It is impossible for normal subjects to make voluntary smooth eye movements without a moving target except under very contrived laboratory conditions (subjects can make voluntary smooth eye movements with "stabilized" images or with an after-image in the dark). This is important because **during saccadic eye movement, visual perception is minimal (2).** Technically, this phenomenon is called "saccadic suppression." You could scan a volume of sky and think that you have eliminated the possibility of danger from that sector and be quite wrong! Think of the eyes as moving from one fixation point to another. In this respect, visual search is considerably different from radar search. The important concept is that between each fixation point acuity falls off sharply, making it possible for targets to go undetected with improper search techniques. This will become clearer as you read on.

Generally, the eye can make about three fixations per second (3). This covers the time to perceive a target and move to another point. Eye movement is much faster than head movement.

<u>Focus</u>

Clear, sharp focus is very important in visual detection. The eye is focused by muscles that control the curvature of the lens. Without visual stimulus, these muscles tend to relax. This would be the case when shifting gaze from inside the cockpit to a featureless blue sky or cloud background. It can result in a focus less than 10 feet away (4). Objects at infinity (for practical purposes optical infinity is anything over 20 feet) will not be correctly imaged on the retina--they will be blurred. The contrast between the object and the background will be reduced as the light from the target is distributed over a larger area. Target contrast, in turn, is the prime factor determining detection range. Out-of-focus eyes can effectively negate the ability to see any aircraft, even your wingman. This problem is easily corrected by first directing the eyes to a distinct, distant object such as a sharp horizon or some cloud or land feature. This will set the correct focus of the lens for subsequent, effective visual search (5).

Peripheral Vision

Central vision is used when looking directly at an object. Peripheral vision is measured in degrees off of this central point. Visual acuity is the ability to distinguish detail in perceived objects. Acuity declines the farther a target is from the central visual axis (6). The relationship between acuity and central and peripheral vision can be displayed as the visual detection lobe, shown in Fig. 2, which represents the range where visual perception of the target can occur (7). It reflects central and peripheral visual detection capability during one fixation under a specific set of conditions. Think of the lobe as being attached to the eye and moving with it during subsequent fixations. It is plotted as a function of probability of detection versus angles off the central visual axis. If the target is inside the lobe, the probability of perceiving it is higher. Chances are that the target will not be seen if it lies well outside of the lobe. Actually, the change in acuity is gradual, and the lobe just represents a given probability of detection. It is a useful mathematical expression to analyze search.

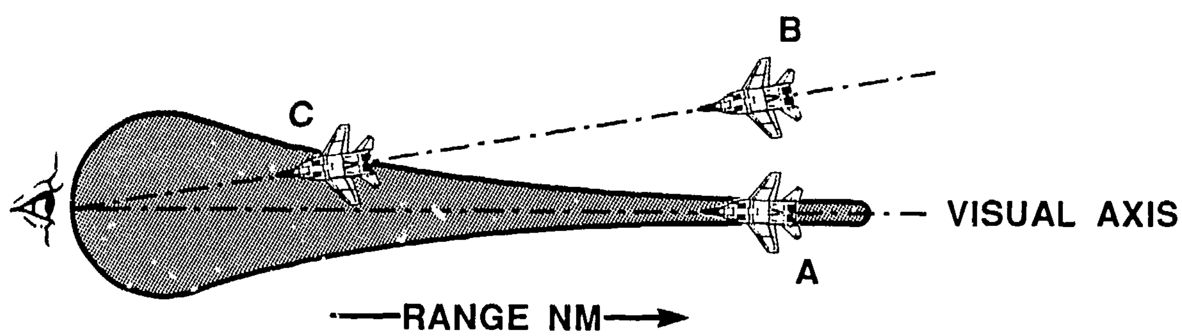

Figure 2. **The visual detection lobe.**

In Fig. 2, consider three locations (A,B,C) of the same type aircraft. Target A can be seen because it lies within the lobe. In fact, it is being directly viewed by central vision. Target B, outside the detection lobe, is at the same range as A. Because it is not being directly viewed and acuity declines rapidly off axis, it cannot be perceived. Target C is the same degree off axis as B, but because it is closer (and hence appears larger), it can be detected in peripheral vision. Once perceived peripherally, the next fixation is likely to be placed right on it. Then, target B will become obvious as it will be well inside of maximum detection range for central vision. Because central vision has such a narrow field of view (less than 2 degrees), peripheral vision is the key to rapid detection, but realize that peripheral vision does not have the detection range of central vision.

Optimizing Detection

To optimize detection, you should examine factors that affect the size of the detection lobe. The main objective is to make threat aircraft easier to see while keeping the fighters hidden.

Target size determines the detection lobe size by increasing or decreasing the visual image size and, hence, the detection range. A head-on aircraft is much harder to see than one with a side or belly view because the image size is smaller. This principle is demonstrated in Fig. 3. Under a very specific set of conditions, this graph estimates the maximum (central acuity) visual detection ranges for several aircraft with extremes of target aspect (front, side, and belly views). This is based on a comprehensive study of fighter pilot vision conducted by the Naval Aerospace Medical Research Laboratory, NAMRL (8).

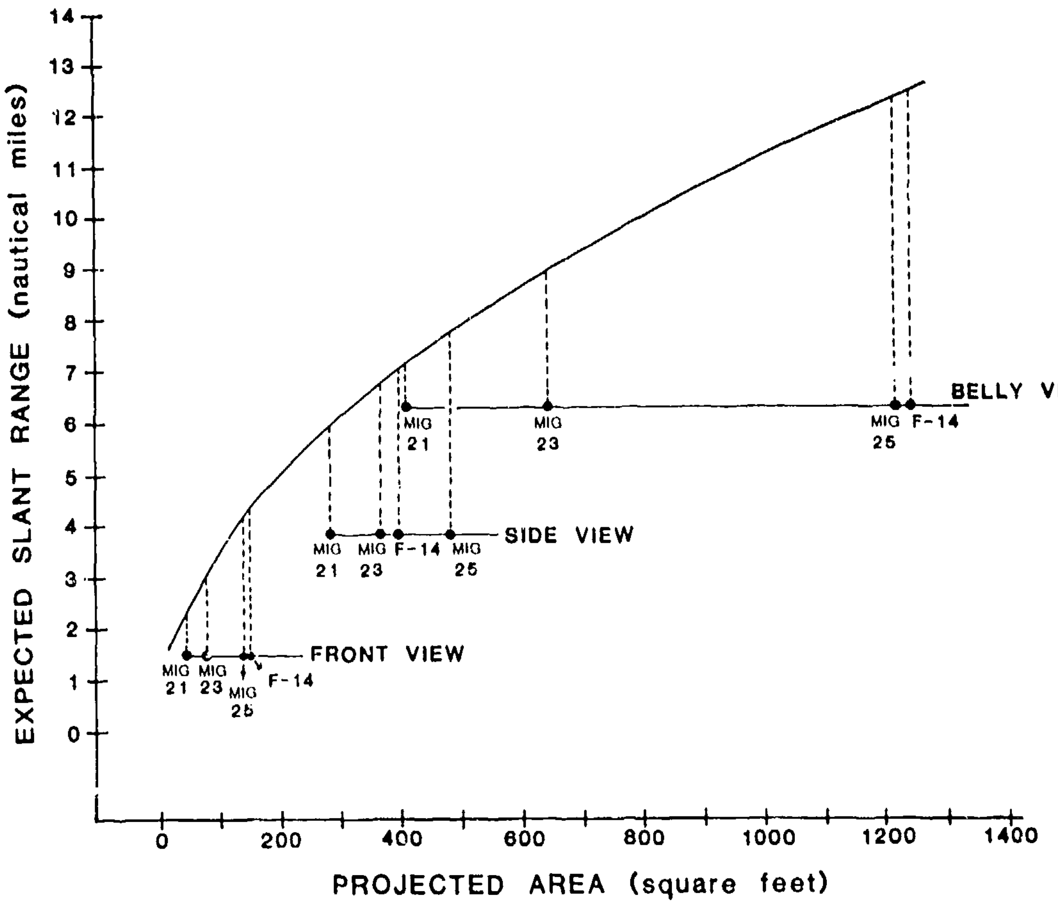

Figure 3. Effect of target aspect on detection range.

For example, a MIG-21 has a head-on projected area of about 40 square feet and an estimated visual detection range of 2.5 nautical miles. In a side view, the projected area increases to about 300 square feet, with an estimated detection range of 6 nautical miles. This increase in the visual image size enables detection to occur at a greater range. For a given aircraft, visual image size is directly related to target aspect. Remember that target aspect is largely determined by fighter intercept geometry. It can drastically influence visual detection. The reverse applies to keeping the fighters hidden. A head-on F-14 has a lower expected detection range than a side or belly view of any of the other aircraft shown above. A head-on fighter is much harder to see than one in planform.

Atmospheric conditions that decrease visibility (e.g., haze, smoke, fog, blowing sand, etc.) will shrink the visual detection lobe (9). There may also be a difference between looking up through the atmosphere or down into it. You should determine atmospheric conditions prior to engagement and make adjustments appropriately.

Relative motion of the target (as measured by increasing or decreasing angles off of the fighter's nose) can enable detection at a greater range. In peripheral vision, a moving target can be perceived at greater range than a static target. Good intercept geometry can prevent the fighters from being highlighted to the bandits by minimizing apparent motion. Abrupt maneuvering of your aircraft can give the enemy a detection advantage even though the angular position of the two aircraft remains relatively stable.

Contrast of the target is one of the prime determinants of detection. Contrast is the ratio of how bright (or dark) the target is relative to the background. A black dot stands out on a white page. Aircraft stand out flying over an undercast.

Sun position can have a profound influence on contrast. A sun glint off a shiny surface offers excellent contrast and can be seen at a great tance. In the NAMRL study, target aircraft were seen an average of 1.4 utical miles farther away when the sun was out of the fighter's visual ield, behind him. The sun was behind the observer in 29 of 30 engagements where the initial visual detection range exceeded 13 nautical miles. The important point is that intercept geometry that considers the position of the sun can put the bandits in a high contrast field by giving the fighters a background to highlight them against. Having the sun behind you also reduces glare and increases the possibility of a long-range sun glint tally ho.

Clutter refers to anything but a uniform background on which to search. Clutter imposes multiple distracters in the visual field and will reduce detection capability (10). Clutter is always present when looking down over land. This is especially true for rough or mountainous terrain. Clutter could also be imposed by a choppy cloud layer or rough seas. In most cases, detection ranges will be decreased.

Aircraft exhaust smoke can aid detection. Smoke provides a relatively large visual target usually contrasted against a blue sky or cloud undercast. A low-angle view of any smoke trail can yield pointing information that maximizes the chance of aircraft detection. In the NAMRL study mentioned above, visual detection of aircraft making smoke occurred an average of 2 nautical miles farther away than aircraft that did not smoke. Aircraft smoke has received much attention over the last several years with a resultant effort to reduce the smoke content in fighter motors. Pilots of F-4 aircraft used to engage the afterburner within 10 nautical miles of intercept, virtually eliminating the visible smoke content of their exhaust (which was considerable when they used military thrust). Pilots of F-14 aircraft have also been using this technique because of the smoke produced by their detuned TF-30 engines. A caveat to remember when considering this technique, however, is the fact that the infrared signature of an aircraft in afterburner is considerably greater than in military thrust. This may present a problem with the re-emergence of IR detectors in aircraft.

Altitude separation between aircraft can affect detection ranges. Generally, with a target aircraft at the same altitude and, therefore, on the horizon, the background haze is uncluttered and provides good contrast. Be aware that the same factor applies to the fighter under observation by the bandit.

SEARCH: USING THE SENSOR

Visual search can be categorized either as localized search or search by exclusion. Localized search occurs when the target is known, and it can be localized by some means. This may result from a GCI call, wingman's call, or a radar lock. Those calls direct visual search to a particular sector. The most localized case would be looking through the diamond/box with a radar lock on target. When searching by exclusion, the fighters are looking for an unknown threat when sector location is also unknown. It is defensive lookout. In any environment, the fighters must be aware of all aircraft near their own. This is primarily accomplished by a diligent and systematic visual search, one that is well integrated into tactics.

Integrating Fixations

Visual search is a series of directed fixations. Each fixation has a particular probability of detection associated with it. The more fixations in a given sector, the greater the probability of detecting a target if present. Each individual fixation requires approximately 275 msec, which limits the total number of fixations. By understanding these concepts, the rules of visual search can be developed. Plotting the visual lobe for three successive fixations would yield a search sequence, as in Fig. 4. The chance of placing the central vision of the eyes directly on a distant bandit is quite remote unless aided by a radar lock or UHF call. This is because the small area of central vision, less than 2 degrees, must be moved over a much larger field in a relatively short time (11). When searching for an aircraft at a closer range (inside of 2 nautical miles), fewer fixations are required because of the enhanced probability of detecting a bandit in peripheral vision. Visual scan can be made more time manageable by widely spaced fixations but at the cost of decreasing the probability of detecting a distant target.

Rules of Visual Search

A large volume of sky will need to be scanned quickly. Basic visual search is a defensive lookout, so all quadrants must be viewed. Other workload requirements will limit the time to scan.

Given a limited amount of time and a large area to search, fixations should be widely spaced to ensure adequate coverage. Do not expect to detect an unknown, pop-up target at your visual acuity limits. If your fixations are widely spaced, you will still pick up the target, but it will be relatively close--probably 1 to 2 nautical miles.

The more time spent searching a sector, the more likely you will be to pick up a long-range tally if one exists in that sector. This is the case for a known, localized aircraft. The fighter will be constrained by the size of the detection lobe and the closure rate between aircraft. With a high rate of closure, time to search is reduced, thus decreasing detection ranges. The time spent intensely searching one sector comes at the expense of others, and this must be considered in the overall tactics.

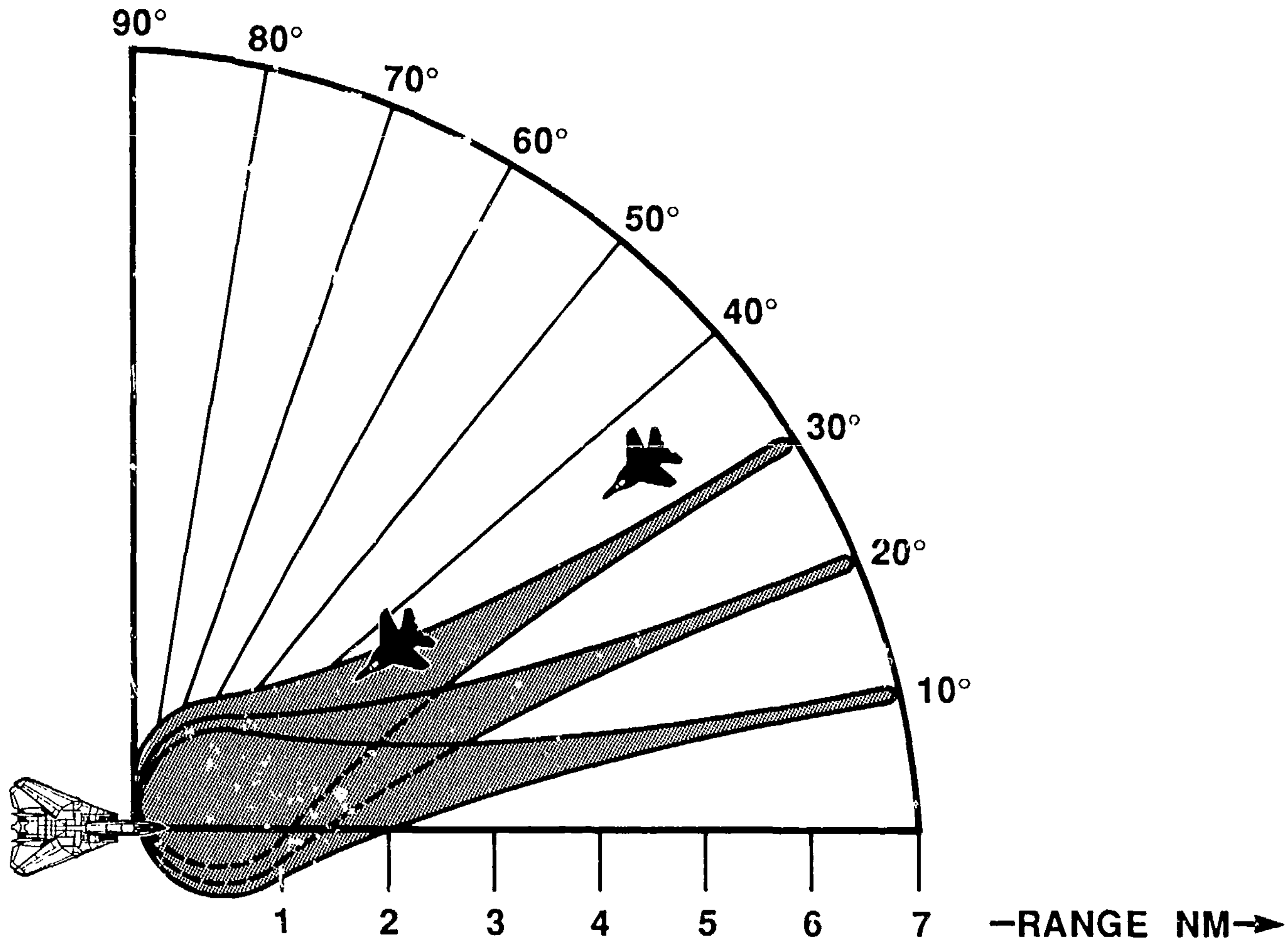

Figure 4. The visual detection lobe during three successive fixations.

Sector Search

The key to visual search is to be systematic. This will not only ensure complete coverage, but it will also enable the visual scan pattern to become a habit. Dividing the total search area around the aircraft into sectors gives the following search plan (Fig. 5).

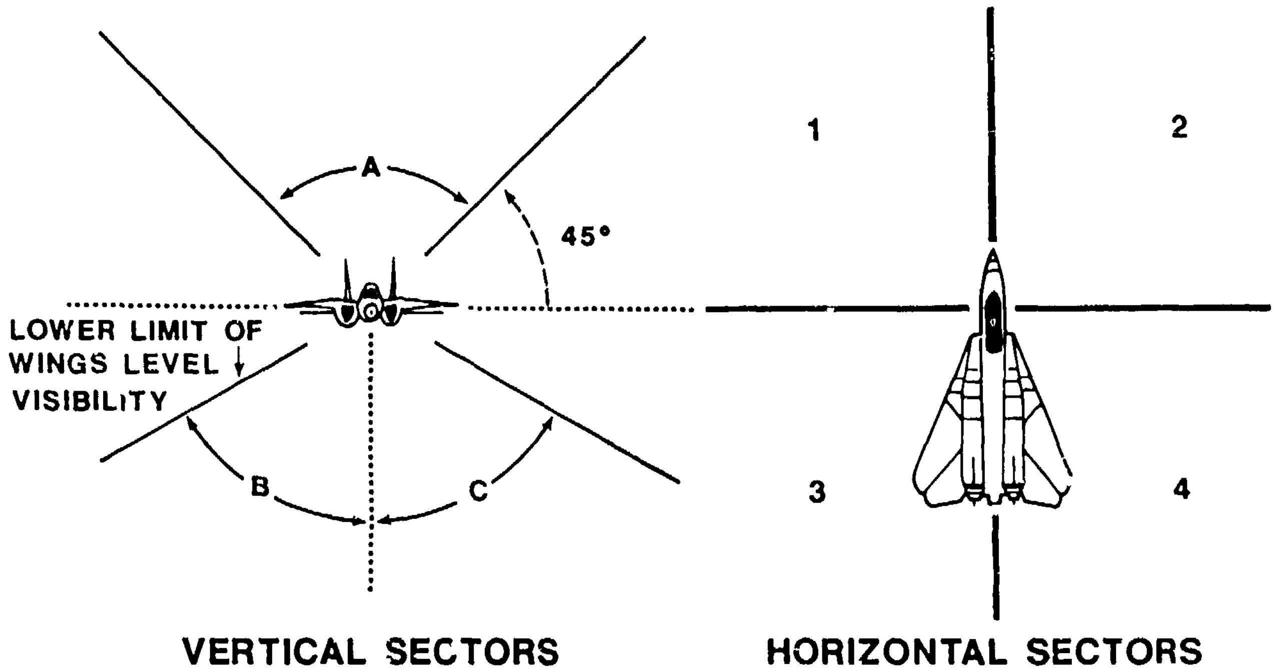

Figure 5. Visual search sectors.

The horizontal sectors are shown divided into 90-degree segments. Depending on the aircraft, these segments could more easily be defined along an aircraft structure, such as a wing line. The vertical extent is from 45 degrees above the horizon to the lower limit of wing-level cockpit visibility. Again, a cockpit indication would be very useful for the upper limit if aircraft structure permits. The two aft sectors check high six. Low six is checked in the two lower vertical sectors. A graphic display of a horizontal search sector is shown in Fig. 6.

The vertical sectors are divided into two groups: the upper and the lower. Searching the upper sector requires considerable twisting around. It is scanned from 45 degrees high in front of the nose to 45 degrees high above the tail. The lower sector requires a wing drop into the sector to be scanned. The aft extent of search needs to include deep six. An upper vertical search sector is shown in Fig. 7.

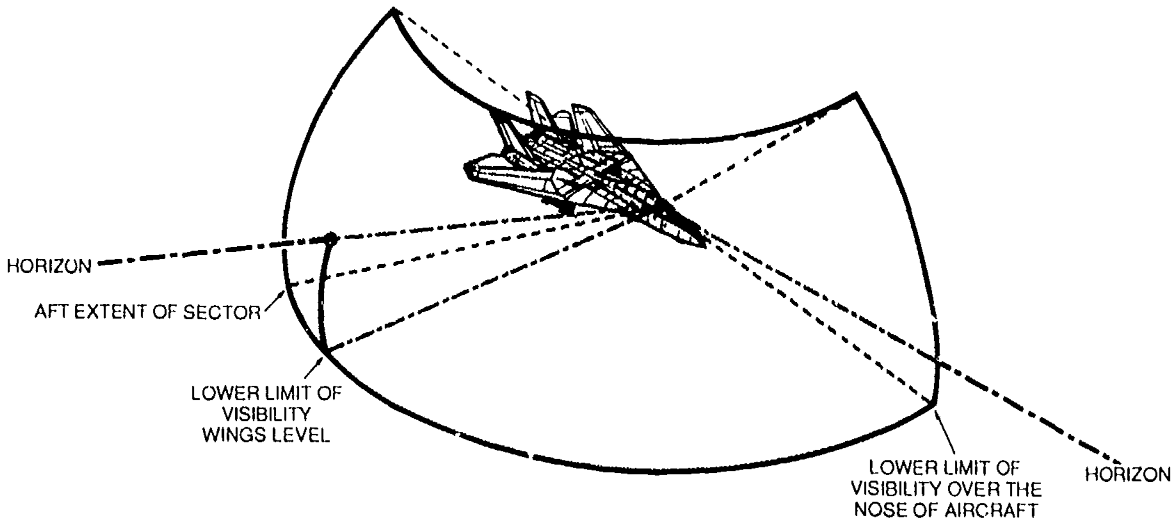

Figure 6. A horizontal search sector.

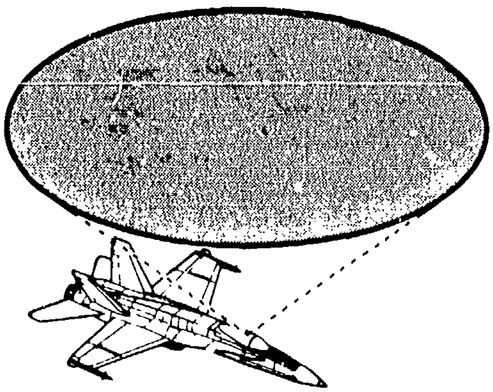

Figure 7. Upper vertical search sector.

The most important variable a fighter must consider is how much time to devote to each sector. As a baseline, consider a 5-second search in each area, which will allow approximately 15 widely spaced fixations per sector. This needs to be planned around the expected threat. With a rear quarter threat, scan should be concentrated in the rear hemisphere, or if a turn is anticipated, scan should be localized around the projected rear hemisphere. A surface-to-air threat suggests that the lower hemisphere will need to be emphasized. The problem becomes more difficult with a forward quarter threat. With the high rate of closure of head-on missiles, the forward sectors will need the emphasis. An incoming forward quarter missile allows the least amount of time to react. A comprehensive study of the ability to detect and respond to these weapons is being conducted by the NAMRL and the NFWS.

Sector Responsibilities

A fighter flying alone will have his visual scan spread very thinly around the sky. If, however, more eyes are available, **scan responsibilities should be assigned within the cockpit and within the section.** This should be a regularly briefed item. With a given volume of sky to search, two sets of eyes can place twice the number of fixations around that volume, thus increasing the probability of detection considerably. Because of aircrew workload, this splitting of responsibilities is very important to the overall search tactics, especially during an intercept. In two-seater aircraft, horizontal scan responsibilities can be split fore and aft. The radar intercept officer (RIO) could be assigned the upper vertical sector while the pilot searches the two lower sectors.

In the section, horizontal responsibilities can be split by assigning the pilot to the two forward sectors and the aft sector in the direction of his wingman. Given the increased workload of directing the intercept, the RIO would have the outside six sector. Again, the RIO would have the upper vertical sectors and the pilot the lower sectors. Suggested horizontal sector assignments are shown in Fig. 8.

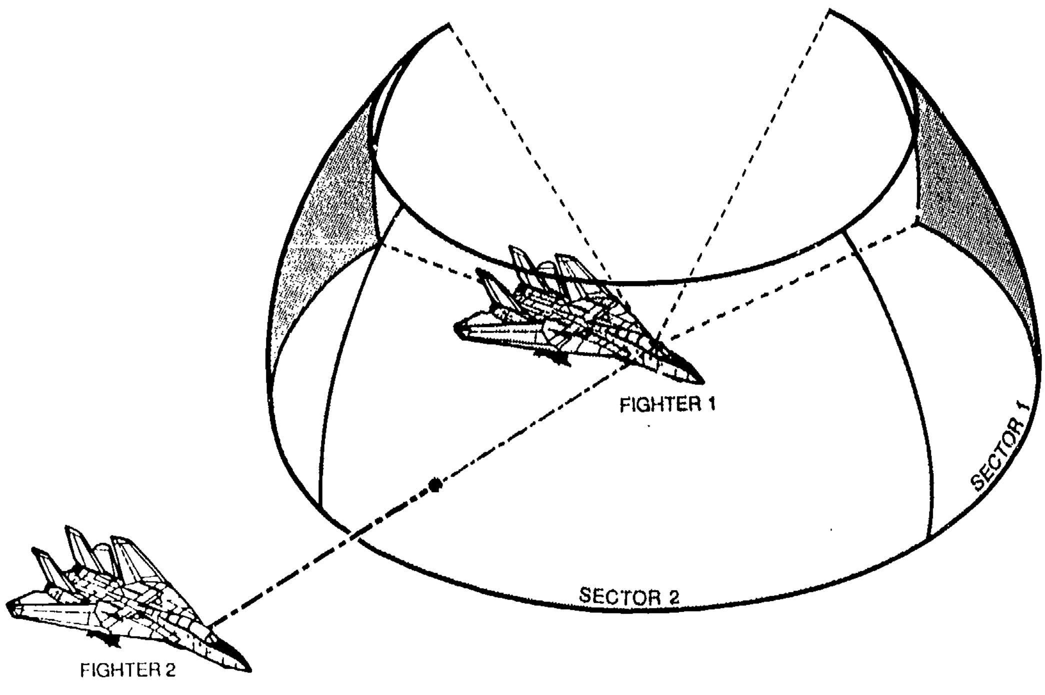

Figure 8. Pilot of Fighter 1 sector scan responsibilities.

Individual Scan Patterns

Research findings in visual search point to the importance of visual cues that provide a reference framework for systematic search. Suggested scan patterns are shown in Fig. 9. They allow complete coverage of the different sectors while providing important reference points. These are just suggestions; further research is needed to determine the most effective search techniques. Regardless, each crew member should develop a scan pattern that assures timely but complete coverage of the assigned sector.

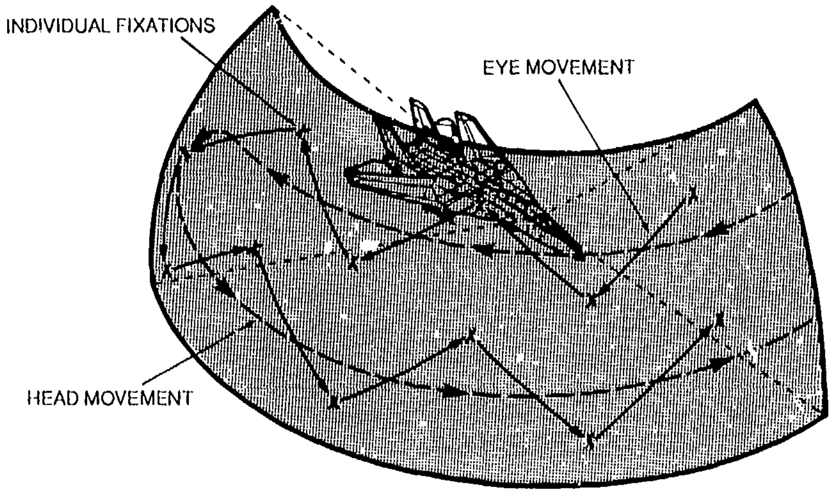

Figure 9. Visual scan patterns for horizontal sectors.

Horizontal Sectors. To scan the horizontal sectors, start scanning forward above the horizon and work aft. Then, scan below the horizon working forward. Use the peripheral view of the horizon and the head position as orientation cues. Remember that scan goes from one fixation point to the next. Although moved quickly, the eyes will stop momentarily to perceive any target at each location. Plan the number of fixations and their spacing within the time allotted to search in this area. Figure 9 shows a representative view of the right horizontal sector. The search pattern is projected onto the scan field.

Vertical Sectors. The task becomes most difficult for the vertical sectors. More than likely, the upper sector will be a uniform field without any visual cues, such as the horizon, to help set the pattern. The best guide will be your sense of head position. With this in mind, work fixations in the same line as head movements. This will ensure that the sector is uniformly scanned. Setting focus at the beginning of search will also be very important. A sample scan pattern for the upper vertical field is shown in Fig. 10. For the two lower sectors, the problem will be ground clutter. This clutter will likely decrease detection ranges unless more time is devoted to search.

In essence, think of each sector as a package to be scanned to completion. As workload dictates, each sector is viewed in sequence. Even if you cannot devote a full 5-second search, at least include a few fixations in each critical sector.

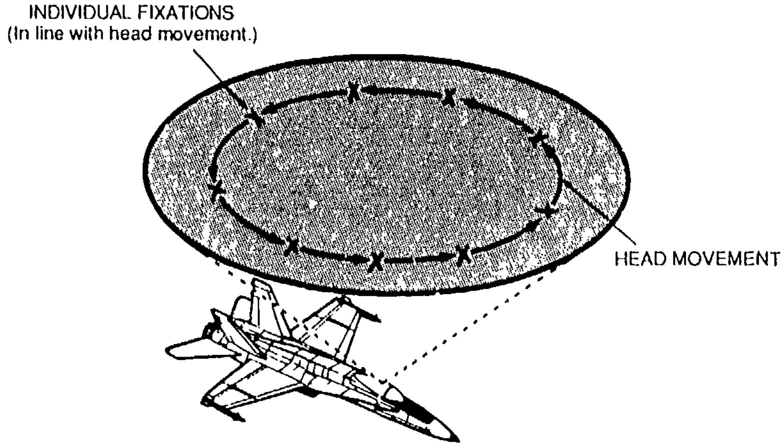

Figure 10. Scan pattern for upper vertical field.

SUMMARY

Visual search and detection is a complex procedure. It requires continuous aircrew participation, and yet it must occur in the high-workload environment of aerial combat. A wise fighter will carefully integrate a visual search strategy into his game plan until it becomes a habit before engaging in aerial combat.

Visual search is a series of discrete fixations, not just rapid eye movements. Remember to set focus at infinity beforehand. To ensure adequate coverage in a limited amount of time, widely space each fixation. Carefully plan the sectors around the aircraft. Set responsibilities for them. Be systematic in your search. Do not neglect sectors that are difficult to view.

To conclude with some important thoughts:

Train to perform visual search the way you intend to search in combat. Vision greatly affects situational awareness in any environment.

Always strive for total awareness of the space around the aircraft. It will pay big dividends in your career as fighter/strike aircrew. Total awareness is primarily accomplished by visual search. Regardless of present or future technological advances, the importance of visual search has not changed since the first days of air combat.

Fleet inputs are needed regarding optimal search and training techniques. As a community, we must exploit this most important sensor. Unfortunately, very little training in visual search is currently available. Even less effort has gone into the visual aspects of tactical development. These shortcomings should be corrected.

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None are applicable.